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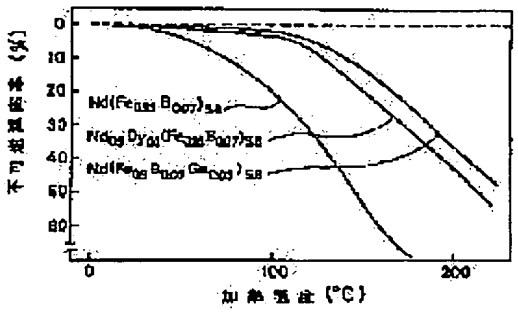
(54) SINTERED PERMANENT MAGNET WITH EXCELLENT HEAT STABILITY

(57)Abstract:
PROBLEM TO BE SOLVED: To remarkably improve IHc and provide a sintered permanent magnet with highly excellent heat stability by providing a magnet wherein the major phase is formed of R2Fe14B type inter-metal compound, intrinsic coersive force (IHc) increases and Curie temperature (Tc) slightly reduces by Ga content, and the contained Ga forms a liquid phase with a rare earth rich phase which surrounds the major phase in sintering.
SOLUTION: A magnet is expressed by the following formula R by atomic ratio; R(Fe1-x-y-z-uCoxByGazMu)A (R is a combination of at least one of Nd, Pr, Ce and other rare earth elements, and M is a combination of at least one of Nb, W, V, Ta and Mo, $0<x\leq0.7$, $0.02\leq y\leq0.3$, $0<Z\leq0.15$, $0\leq u\leq0.1$, $4.0\leq A\leq7.5$), the major phase is R2Fe14B type inter-metal compound, and intrinsic coersive force (IHc) is increased and Curie temperature (Tc) is reduced by Ga content. The Ga contained at sintering forms a liquid phase with a rare earth rich phase and the magnet is sintered.



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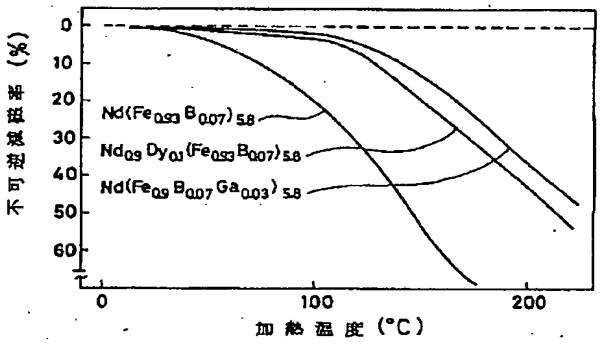
(54)【発明の名称】　熱安定性の良好な焼結型永久磁石

(57)【要約】
【課題】　主相が$R_2Fe_{14}B$型金属間化合物であり、Ｇａの含有により固有保磁力（ＩＨｃ）が増大しキュリー温度（Ｔｃ）がやや低下する作用を有し、含有されるＧａが焼結時において主相を取り囲む希土類リッチ相とともに液相を形成して焼結されることによってｉＨｃを著しく高め、極めて良好な熱安定性を付与した焼結型永久磁石を提供する。
【解決手段】　原子比で式$R(Fe_{1-x-y-z-u}Co_xB_yGa_zM_u)_A$（ここでＲはＮｄ，Ｐｒ，Ｃｅその他の希土類元素の１種以上の組み合わせ、ＭはＮｂ，Ｗ，Ｖ，Ｔａ，Ｍｏの１種以上の組み合わせ、$0<x\leqq0.7$、$0.02\leqq y\leqq0.3$、$0<z\leqq0.15$、$0\leqq u\leqq0.1$、$4.0\leqq A\leqq7.5$）で表され、主相が$R_2Fe_{14}B$型金属間化合物であり、Ｇａの含有により固有保磁力（ＩＨｃ）が増大しキュリー温度（Ｔｃ）が低下する作用を有し、焼結時において含有されるＧａが希土類リッチ相とともに液相を形成し焼結されたことを特徴とする熱安定性の良好な焼結型永久磁石。



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【特許請求の範囲】

【請求項１】　原子比で式Ｒ（$Fe_{1-x-y-z-u}Co_xB_yGa_zM_u$）$_A$（ここでＲはＮｄ，Ｐｒ，Ｃｅその他の希土類元素の１種または２種以上の組み合わせ、ＭはＮｂ，Ｗ，Ｖ，Ｔａ，Ｍｏの１種または２種以上の組み合わせ、$0<x\leqq0.7$、$0.02\leqq y\leqq0.3$、$0<z\leqq0.15$、$0\leqq u\leqq0.1$、$4.0\leqq A\leqq7.5$）で表され、主相が$R_2Fe_{14}B$型金属間化合物であり、Ｇａの含有により固有保磁力（ＩＨｃ）が増大しキュリー点（Ｔｃ）が低下する作用を有し、焼結過程において含有されるＧａが希土類リッチ相とともに液相を形成し焼結されてなることを特徴とする熱安定性の良好な焼結型永久磁石。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、主相が$R_2Fe_{14}B$型金属間化合物であり、Ｇａの含有により固有保磁力（ＩＨｃ）が増大しキュリー点（Ｔｃ）が低下する作用を有し、含有されるＧａが焼結過程においてＲリッチ相とともに液相を形成し焼結されてなることによりＩＨｃを著しく高め、極めて良好な熱安定性を付与した焼結型永久磁石に関する。

【０００２】

【従来の技術】Ｒ－Ｆｅ－Ｂ系永久磁石材料は、Ｒ－Ｃｏ系永久磁石材料よりも高い磁気特性が得られる新しい組成系として開発が進んでおり、数多くの発明が提案されている。例えば$Nd_{15}Fe_{77}B_8$［組成式表示で$Nd(Fe_{0.91}B_{0.09})_{5.67}$］は最大磁気エネルギー積（ＢＨ）maxが35MGOe，固有保磁力ＩＨｃが10KOeに達する磁気特性を得ている（J. Appl. Phys. 55(6) 2083(1984)参照。）

しかしながら、開発初期に提案されたＲ－Ｆｅ－Ｂ系永久磁石はキュリー点（Ｔｃ）が低く、そのため熱安定性が悪いという欠点がある。すなわち、従来のＲ－Ｃｏ系の永久磁石では約800℃のＴｃを有するのに対し、開発初期に提案されたＲ－Ｆｅ－Ｂ系永久磁石材料では通常Ｔｃが約300℃程度であり、最高でも370℃程度と極めて低い（特開昭59-46008号公報参照）。従って、熱安定性が不十分であって、周囲温度が高い環境下での使用には難点があった。それを解決する手段としては、直接Ｔｃを向上させること、室温における固有保磁力（ＩＨｃ）を十分高くすることによって高温での減磁分があっても耐えられるようにすることの２つが知られている。

【０００３】前者として、Ｆｅの一部をＣｏで置換することによってＴｃを上げる試みがなされた。その結果、Ｔｃを400℃以上で、磁気特性を犠牲にすれば800℃にまでも上昇させる効果が認められた（特開昭59-64733号公報参照）。後者として、Ａｌ，Ｔｉ，Ｖ，Ｃｒ，Ｍｎ，Ｚｎ，Ｈｆ，Ｎｂ，Ｔａ，Ｍｏ，Ｇｅ，Ｓｂ，Ｓｎ，Ｂｉ，Ｎｉ等の添加が行われてきた。中でもＡｌはＩＨｃ

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向上に特に有効とされる（特開昭59-89401号、60-77960号公報参照）。さらにＴｂ，Ｄｙ，Ｈｏのような重希土類元素によるＮｄの一部置換が高い最大エネルギー積［（ＢＨ）max］を保持しつつＩＨｃを改善するために提案されており、約30MGOeの（ＢＨ）maxのときＩＨｃが9KOe程度のものが12～18KOeに増大される（特開昭60-32306，60-34005号公報参照）。加えて、ＣｏとＡｌの複合添加が熱安定性向上の手段として提案されている。すなわち、Ｆｅの一部をＣｏで置換するとＴｃは向上するが、反面ＩＨｃの低下が否めない。それは、Ｎｄ（Ｆｅ，Ｃｏ）$_2$で表わされる磁性を持った析出物が結晶粒界に現われ逆磁区が発生してＩＨｃを低下するためと考えられている。そこで、ＣｏにＡｌを複合添加することによって非磁性のＮｄ（Ｆｅ，Ｃｏ，Ａｌ）$_2$で表わされる相を出現させることによって逆磁区を発生させない試みも行われている（Appl. Phys. Lett. 48(19), 1309(1986)）。

【０００４】

【発明が解決しようとする課題】しかし、前述の従来技術には次に述べる問題点がある。

①ＣｏによるＦｅの一部置換の場合

結晶磁気異方性を低下させるためＩＨｃを低下する。また、原料面からコスト高、供給不安がある。

②Ａｉ，Ｔｉ，Ｖ，Ｎｉ等を添加する場合

Ｎｉを除いて非磁性材料であるため、多量の添加は残留磁束密度$4\pi Ir$の低下を招来し、（ＢＨ）maxを下げる。Ｎｉも、強磁性材料ではあるが磁気モーメントが小さいため、結局$4\pi Ir$を低下する。

③重希土類元素を添加する場合

非常に高価であるためコストの著しい上昇を伴なう。資源的希少性に加えて永久磁石以外の用途が少ないためである。

④ＣｏとＡｌを複合添加する場合

Ａｌの添加はＴｃを著しく低下させるため、100℃以上における高温での熱安定性に劣る。加えて、ＣｏとＡｌを複合添加したＲ－Ｆｅ－Ｂ系磁石のＩＨｃは、たかだか12KOe程度にすぎない。

【０００５】従って、本発明の課題は、主相が$R_2Fe_{14}B$型金属間化合物であり、Ｇａの含有により固有保磁力（ＩＨｃ）が増大しキュリー温度（Ｔｃ）が低下する作用を有し、含有されるＧａが焼結時において主相を取り囲む希土類リッチ相とともに液相を形成して焼結されることによってＩＨｃを著しく高め、極めて良好な熱安定性を付与した焼結型永久磁石を提供することである。

【０００６】

【課題を解決するための手段】上記従来の課題を解決した本発明は、原子比で式Ｒ（$Fe_{1-x-y-z-u}Co_xB_yGa_zM_u$）$_A$（ここでＲはＮｄ，Ｐｒ，Ｃｅその他の希土類元素の１種または２種以上の組み合わせ、ＭはＮｂ，Ｗ，Ｖ，Ｔａ，Ｍｏの１種または２種以上の組み合わ

せ、０＜ｘ≦０．７、０．０２≦ｙ≦０．３、０＜ｚ≦０．１５、０≦ｕ≦０．１，４．０≦Ａ≦７．５）で表され、主相が$R_2Fe_{14}B$型金属間化合物であり、Ｇａの含有により固有保磁力（ＩＨｃ）が増大しキュリー点（Ｔｃ）が低下する作用を有し、焼結過程において含有されるＧａが主相を取り囲む希土類リッチ相とともに液相を形成し焼結されてなることを特徴とする熱安定性の良好な焼結型永久磁石である。上記、本発明磁石において、０＜ｘ≦０．７、０．０２≦ｙ≦０．３、０．００１≦ｚ≦０．１５、０≦ｕ≦０．１，４．０≦Ａ≦７．５とすることが熱安定性の点からより好ましい。また、０＜ｘ≦０．３９、０．０３≦ｙ≦０．２、０．００２≦ｚ≦０．１、０．００２≦ｕ≦０．０４、４．５≦Ａ≦７とすることが熱安定性の向上の点から特に好ましい。また、ＲがＮｄでｕ＝０の場合、０＜ｘ≦０．３９、０．０３≦ｙ≦０．２、０．００２≦ｚ≦０．１、４．５≦Ａ≦７とすることが良好な熱安定性を得るために好ましい。

【０００７】希土類元素ＲはＮｄ，Ｐｒ，Ｃｅその他の希土類元素であって、特にＮｄを主体としてＰｒ，Ｃｅのような軽希土類元素またはＤｙのような重希土類元素で一部置換できる。なお、Ｈｏ，Ｔｂなどの重希土類元素も利用できる。

Ｎｄの一部をＰｒで置換する場合には原子比率で98％を越えると４πＩｒが低下し、Ｎｄの一部をＣｅで置換する場合には、原子比率で30％を越えると４πＩｒが低下する。Ｎｄの一部をＤｙで置換する場合には原子比率で3％未満ではＩＨｃ向上効果すなわち熱安定性がなく、5％以上25％以下の置換によって最も好ましい効果があるが、40％を越える置換は４πＩｒを低下するため好ましくない。

【０００８】本発明において、硼素Ｂの含有量ｙが0.02未満だとＴｃが低くなり、かつ十分な保磁力が得られない。他方、ｙが0.3を超えると４πＩｓが低下し、磁気特性に悪影響を及ぼす相が出現する。従って、ｙは0.02～0.3であり、より好ましくは0.03～0.2、最も好ましくは0.04～0.15である。

【０００９】本発明において、Ｇａの添加はＩＨｃ向上に顕著な効果がある。この効果はＲ－Ｆｅ－Ｂ系磁石の主相（金属間化合物$Nd_2Fe_{14}B$等。）を取り囲むＲリッチ相と密接に関係があると考えられる。

Ｇａの含有量ｚは良好な熱安定性を確保するために０＜ｚ≦0.15とするのがよく、0.001≦ｚ≦0.15とするのがより好ましく、0.002≦ｚ≦0.10とするのがさらに好ましく、0.005≦ｚ≦0.05とすることが特に好ましい。Ｇａの含有量ｚが0.15を超えると飽和磁化４πＩｓとＴｃの著しい減少を呈し好ましくない。

【００１０】本発明において、Ｃｏは必須であり、Ｔｃ向上効果があるためＧａと複合添加することによって熱安定性の際だった向上に効果がある。ｘで示されるＣｏの含有量が0.7を超えると磁石の４πＩｒ、ＩＨｃが低下して好ましくない。ＩＨｃと４πＩｒおよびＴｃの良好な均衡のためのＣｏの好ましい上限は0.39であり、最も好ましくは0.25である。

【００１１】本発明磁石には、添加元素Ｍ：Ｎｂ，Ｗ，Ｖ，Ｔａ，Ｍｏを結晶粒の粗大化防止のために添加することができる。なかでも、ＮｂとＷの効果が最も優れている

。Ｎｂの添加は４πＩｒを若干低下するが、Ｇａほど４πＩｒを低下させない。また、Ｎｂは耐蝕性向上にも効果があるため、比較的高温にさらされる高耐熱永久磁石にとって非常に有効な元素である。原子比で式$R(Fe_{1-x-y-z-u}Co_xB_yGa_zM_u)_A$（ここでＲは希土類元素の１種または２種以上の組み合わせ、ＭはＮｂ，Ｗ，Ｖ，Ｔａ，Ｍｏの1種または２種以上の組み合わせ、０＜ｘ≦０．７、０．０２≦ｙ≦０．３、０＜ｚ≦０．１５、０≦ｕ≦０．１、４．０≦Ａ≦７．５）で表され、ＭがＮｂであり含有量ｕが0.001未満のときはＩＨｃの十分な向上効果が得られず、また、十分な耐蝕性を示さない。他方、0.1を超えるときは４πＩｒとＴｃの好ましくない減少を招来する。Ｎｂのより好ましい範囲は0.002～0.04である。Ｗの添加も熱安定性を著しく向上する。ｕで示されるＷの量が0.1を超えるときは、４πＩｓおよびＩＨｃが著しく低下する。そして、0.001未満のときはＩＨｃの十分な向上効果が得られない。より好ましい範囲は0.002～0.04である。Ｖ，Ｔａ，Ｍｏの添加も有効であり、ｕが0.001未満のときには十分なＩＨｃ向上効果が得られず、0.1を超えるときには４πＩｓが著しく減少する。より好ましい範囲は0.002～0.04である。

【００１２】本発明において、Ａが4未満のときは４πＩｓが低く、7.5を超えるときはＦｅとＣｏリッチな相が出現し、保磁力を著しく低下させる。従って、Ａは4～7.5であり、より好ましくは4.5～7、最も好ましくは5.0～6.8である。

【００１３】

【発明の実施の形態】以下、実施例により本発明を説明する。

【００１４】（実施例１）$Nd(Fe_{0.70}Co_{0.2}B_{0.07}Mo_{0.03})_{6.5}$（ただし、Ｍ＝Ｂ，Ａｌ，Ｓｉ，Ｐ，Ｔｉ，Ｖ，Ｃｒ，Ｍｎ，Ｃｕ，Ｇａ，Ｇｅ，Ｚｒ，Ｎｂ，Ｍｏ，Ａｇ，Ｉｎ，Ｓｂ，Ｗのいずれか１種）なる組成の合金をアーク溶解にて作製した。得られたインゴットをスタンプミルおよびディスクミルで粗粉砕した。粉砕媒体としてN_2ガスを用いジェットミルで微粉砕を行い粉砕粒度3.5μｍ（ＦＳＳＳ）の微粉砕粉を得た。得られた原料粉を15KOeの磁場中で横磁場成形（プレス方向と磁場方向が直交）した。成形圧力は2ﾄﾝ/cm²であった。本成形体を真空中で1090℃×2時間焼結した。熱処理は500～900℃に1時間加熱保持した後、急冷した。

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得られた結果を表１に示す。検討した１９元素の中でＩＨｃが10KOeを超えるものはＧａだけである。このようにＧａは保磁力の向上に非常に有効である。表１において、本発明に属するＭ＝Ｇａ添加の場合のＴｃ＝４６８℃に対し、Ｍ＝Ｂ添加のもののＴｃ＝４７７℃であり、＊

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＊Ｇａの含有によってＴｃがやや低下する作用を有していることがわかる。

【００１５】

【表１】

$Nd(Fe_{0.7}Co_{0.2}B_{0.07}M_{0.03})_{5.5}$ 磁石の磁気特性

M	B	Al	Si	P	Ti	V	Cr	Mn	Ni	Cu
4πIs (KG)	13.31	12.61	12.80	12.90	12.77	13.19	12.30	12.50	12.95	12.57
4πIr (KG)	12.80	12.45	12.65	0	11.80	13.05	12.15	12.34	12.78	12.32
iHc (KOe)	2.6	8.5	7.0	0	4.8	4.9	5.1	5.3	4.1	3.0
(BH)max (MGOe)	13	33.5	32.0	0	24.0	25.5	28.0	24.0	13.1	18.1
Tc (℃)	477	460	458	482	467	470	478	431	485	481

Tc：キュリー点

M	Ga	Ge	Zr	Nb	Mo	Ag	In	Sb	W
4πIs (KG)	12.60	12.72	12.30	13.03	13.10	13.22	12.70	12.05	12.95
4πIr (KG)	12.50	～0	10.5	12.9	～0	～0	～0	～0	12.75
iHc (KOe)	16.0	～0	4.3	6.9	～0	～0	～0	～0	6.0
(BH)max (MGOe)	35.0	～0	12.1	35.1	～0	～0	～0	～0	32.2
Tc (℃)	468	479	466	477	465	483	488	482	476

【００１６】（実施例２）$Nd(Fe_{0.9-x}Co_xB_{0.07}Ga_{0.03})_{5.8}$（ｘ＝0～0.75）および比較例として$Nd(Fe_{0.93-x}Co_xB_{0.07})_{5.8}$（ｘ＝0～0.25）、$Nd_{0.9}Dy_{0.1}(Fe_{0.93-x}Co_xB_{0.07})_{5.8}$（ｘ＝0～0.25）なる組成の合金を実施例1と同様な方法で粗粉砕、微※

※粉砕、焼結、熱処理した。得られた結果を表２、表３、表４に示す。これらの結果からＣｏの添加量ｘは０．７以下で適当であることがわかる。

【００１７】

【表２】

$Nd(Fe_{0.9-x}Co_xB_{0.07}Ga_{0.03})_{5.8}$ 磁石の磁気特性

磁気特性＼x	0	0.01	0.05	0.25	0.39	0.7	0.75
4πIr (KG)	12.6	12.58	12.55	12.09	12.02	10.7	9.2
iHc (KOe)	20.6	19.9	19.6	16.5	14.8	12.3	11.0 s
(BH)max (MGOe)	37.0	36.6	36.2	33.2	32.8	26.6	19.2

【００１８】

【表３】

$Nd(Fe_{0.93-x}Co_xB_{0.07})_{5.8}$ 磁石の磁気特性（比較例）

磁気特性＼x	0	0.01	0.05	0.25
4πIr (KG)	13.4	13.32	13.32	12.88
iHc (KOe)	9.0	8.8	8.8	7.1
(BH)max (MGOe)	42.1	41.5	41.5	38.8

【００１９】

【表４】

$Nd_{0.9}Dy_{0.1}(Fe_{0.93-x}Co_xB_{0.07})_{5.8}$ 磁石の磁気特性（比較例）

磁気特性＼x	0	0.01	0.05	0.25
4πIr (KG)	12.62	12.59	12.51	12.11
iHc (KOe)	15.6	15.4	15.0	11.6
(BH)max (MGOe)	38.2	37.9	37.5	34.3

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【００２０】次に、Ｃｏ量が0および0.2の場合における試料を所定温度に30分間加熱保持後、open　fluxの変化を測定し、熱安定性を調べた。測定に用いた試料はパーミアンス係数Ｐｃ＝－２となる形状に加工したものである。得られた結果を図1、図2に示す。明らかにＧａを加えると保磁力が高く熱安定性は非常に改善される。

【００２１】（実施例３）Ｎｄ（$Fe_{0.7}Co_{0.2}B_{0.08}Ga_{0.02}$）$_A$（Ａ＝3.7～7.7）、Ｎｄ（$Fe_{0.92}B_{0.08}$）$_A$（Ａ＝5.6～6.6）なる組成の合金を実施例1と同様な方法で粗粉砕、微粉砕、焼結、熱処理した。得られた結果を表５（ａ）、表５（ｂ）に示す。Ｎｄ－＊

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＊Ｆｅ－Ｂ3元系の場合、Ａ＝6.2以上においてはＩＨｃ、(BH)maxはほとんどゼロであるのに対し、Ｃｏ，Ｇａを複合添加することにより、Ａ＝6.6以上でも高保磁力が得られ、高特性が得られる。Ｎｄ－Ｆｅ－Ｂ3元系は、Ａ＝6.2以上においてはＮｄの酸化により焼結過程で液相として働くＮｄリッチ相が減少することが原因となって、保磁力の発生を妨げている。。これに対し、Ｃｏ，Ｇａ複合添加の場合、Ｇａが酸化したＮｄの代りに液相として働き、高保磁力を発生させている。

【００２２】

【表５】

(a)　Nd（$Fe_{0.7}Co_{0.2}B_{0.08}Ga_{0.02}$）$_A$ 磁石の磁気特性

磁気特性＼A	3.7	4.0	5.6	6.6	7.5	7.7
4πIr（KG）	9.2	10.4	12.25	12.7	13.8	14.0
iHc（KOe）	17.5	17.3	15.4	12.0	10.7	5.9
(BH)max（MGOe）	19.2	25.0	35.8	37.1	45.6	15.8

(b)　Nd（$Fe_{0.92}B_{0.08}$）$_A$ 磁石の磁気特性（比較例）

磁気特性＼A	5.6	5.8	6.0	6.2	6.4	6.6
4πIr（KG）	13.04	13.2	13.4	13.6	13.7	13.8
iHc（KOe）	10.0	9.3	9.0	0	0	0
(BH)max（MGOe）	40.2	41.3	42.6	0	0	0

【００２３】（実施例４）（$Nd_{0.8}Dy_{0.2}$）（$Fe_{0.86-z}Co_{0.06}B_{0.08}Ga_z$）$_{5.5}$（ｚ＝0～0.18）なる合金を実施例１と同様な方法で溶解、粉砕、成形、焼結した。さらに、900℃×2時間の加熱保持後、1.5℃／minで常温まで冷却した後、580℃×1時間の時効処理をAr気流中で行い水中で冷却した。得られた磁気特性を表６に示し、220℃加熱による不可逆減磁率を表７に示す。Ｇａの添加により４πＩｒ、(BH)maxは低下していくがＩ　※

※Hcは大幅に上昇し、耐熱性も向上していることがわかる。Ｇａの添加量ｚは0.001で効果が認められ、0.15を越えると４πＩｒが顕著に減少するので0＜ｚ≦0.15が好ましく、0.001≦ｚ≦0.15とするのがより好ましく、0.002≦ｚ≦0.10とするのがさらに好ましく、0.005≦ｚ≦0.05とすることが特に好ましい。

【００２４】

【表６】

$(Nd_{0.8}Dy_{0.2})(Fe_{0.86-z}Co_{0.06}B_{0.08}Ga_z)_{5.5}$

z	4πIr（G）	bHc（Oe）	iHc（Oe）	(BH)max (MGOe)
0	11050	10700	22500	29.5
0.001	11000	10650	23200	29.6
0.002	10900	10600	23500	28.8
0.005	10740	10400	25200	27.9
0.01	10600	10200	26500	27.2
0.05	9400	9600	27200	20.1
0.10	8900	8600	＞28000	18.9
0.15	8000	7800	＞28000	15.3
0.18	7200	7600	＞28000	11.0

【００２５】

【表７】

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$(Nd_{0.9}Dy_{0.1})(Fe_{0.845-z}Co_{0.06}B_{0.08}Ga_z)_{5.5}$

z	220℃加熱による不可逆減磁率（%，Pc＝－2）
0	10.1
0.001	9.3
0.002	7.5
0.005	5.1
0.01	2.7
0.05	1.9
0.10	0.3
0.15	0.1
0.18	0.1

【００２６】（実施例５）（$Nd_{0.9}Dy_{0.1}$）（$Fe_{0.845-z}Co_{0.06}B_{0.08}Nb_{0.015}Ga_z$）$_{5.5}$（z＝0～0.06）なる合金を実施例１と同様な方法で溶解、粉砕、成形、焼結、熱処理した。得られた磁気特性を表８に示し、220℃加熱による不可逆減磁率を表９に示す。Ｄｙ置換量の少ない場合においてもＧａの添加により熱安定性は向上することがわかる。また、Ｇａの添加量は0.001で効果が認められ、0.15を越えると４πＩｒが著しく＊減少することがわかる。従って、Ｇａの添加量ｚは0＜ｚ≦0.15が好ましく、0.001≦ｚ≦0.15とするのがより好ましく、0.002≦ｚ≦0.10とするのがさらに好ましく、0.005≦ｚ≦0.05とすることが特に好ましいことがわかる。

【００２７】

【表８】

$(Nd_{0.9}Dy_{0.1})(Fe_{0.845-z}Co_{0.06}B_{0.08}Nb_{0.015}Ga_z)_{5.5}$

z	4πIr（G）	bHc（Oe）	iHc（Oe）	(BH)max (MGOe)
0	11850	11550	15200	34.1
0.001	11800	15200	16700	33.8
0.002	11670	11440	17400	32.4
0.005	11580	11260	18760	32.0
0.01	11400	11000	19800	31.6
0.05	10550	10100	＞28000	26.9
0.10	10000	9880	＞28000	25.2
0.15	8550	8320	＞28000	22.4
0.18	7560	7240	＞28000	20.8

【００２８】

【表９】

$(Nd_{0.9}Dy_{0.1})(Fe_{0.845-z}Co_{0.06}B_{0.08}Nb_{0.015}Ga_z)_{5.5}$

z	220℃加熱による不可逆減磁率（%，Pc＝－2）
0	38.1
0.001	34.4
0.002	32.6
0.005	29.7
0.01	20.3
0.05	0.7
0.10	0.6
0.15	0.6
0.18	0.5

【００２９】

【発明の効果】以上、実施例に示したように、従来のＲ－Ｆｅ－Ｂ系焼結磁石においては含有される希土類元素Ｒの酸化により焼結過程で液相として働くＲリッチ相が減少することが原因となって有効な未酸化の含有Ｒ分が不足した状態で焼結されるために保磁力が著しく減少するのに対し、本発明磁石においては焼結過程において未酸化の有効な含有Ｒ分の不足を補うように含有されているＧａが液相として存在し焼結が進行するために極めて高いＩＨｃを発現し際立って良好な熱安定を獲得することができる。

【図面の簡単な説明】

【図１】Ｎｄ－Ｆｅ－Ｂ、Ｎｄ－Ｄｙ－Ｆｅ－ＢおよびＮｄ－Ｆｅ－Ｂ－Ｇａ磁石の加熱温度に対する不可逆減磁率を示す図である。

【図２】Ｎｄ－Ｆｅ－Ｃｏ－Ｂ、Ｎｄ－Ｄｙ－Ｆｅ－Ｃ

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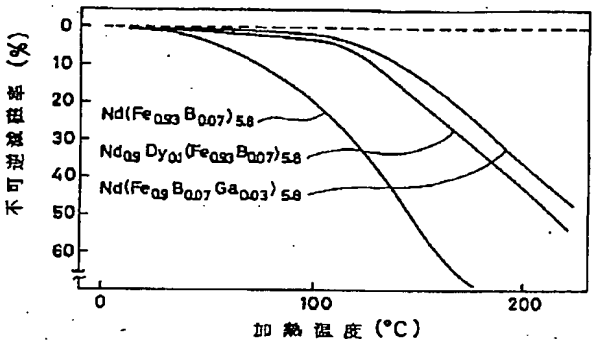
ｏ－ＢおよびＮｄ－Ｆｅ－Ｃｏ－Ｂ－Ｇａ磁石の加熱温

【図１】



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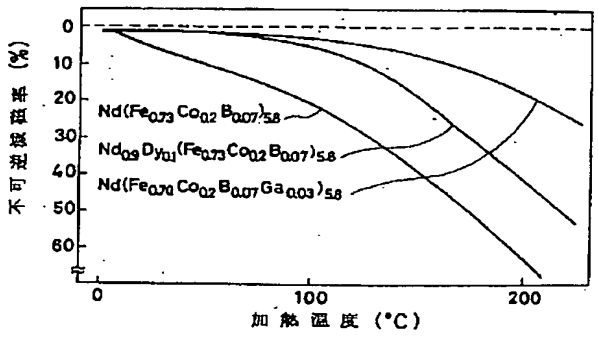
度に対する不可逆減磁率を示す図である。

【図２】



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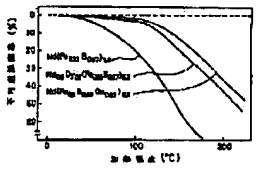
(71)Applicant : HITACHI METALS LTD

(72)Inventor : ENDO MINORU

TOKUNAGA MASAAKI

KOGURE HIROSHI

(54) SINTERED PERMANENT MAGNET WITH EXCELLENT HEAT STABILITY



(57)Abstract:

PROBLEM TO BE SOLVED: To remarkably improve IHc and provide a sintered

permanent magnet with highly excellent heat stability by providing a magnet wherein the major phase is formed of R2Fe14B type inter-metal compound, intrinsic coersive force (IHc) increases and Curie temperature (Tc) slightly reduces by Ga content, and the contained Ga forms a liquid phase with a rare earth rich phase which surrounds the major phase in sintering.
SOLUTION: A magnet is expressed by the following formula R by atomic ratio; R(Fe1-x-y-z-uCoxByGazMu)A (R is a combination of at least one of Nd, Pr, Ce and other rare earth elements, and M is a combination of at least one of Nb, W, V, Ta and Mo, $0<x\leq0.7$, $0.02\leq y\leq0.3$, $0<Z\leq0.15$, $0\leq u\leq0.1$, $4.0\leq A\leq7.5$), the major phase is R2Fe14B type inter-metal compound, and intrinsic coersive force (IHc) is increased and Curie temperature (Tc) is reduced by Ga content. The Ga contained at sintering forms a liquid phase with a rare earth rich phase and the magnet is sintered.

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CLAIMS

[Claim(s)]

[Claim 1] an atomic ratio -- formula R(Fe1-x-y-z-uCoxByGazMu) A (here -- R -- one sort or two sorts or more of combination of the rare earth elements of Nd, Pr, and Ce and others --) M One sort or two sorts or more of combination of Nb, W, V, Ta, and Mo, It is expressed with 0< x<=0.7, 0.02<=y<=0.3, 0< z<=0.15, 0<=u<=0.1, and 4.0<=A<=7.5. The main phase is an R2Fe14B mold intermetallic compound, and it has the operation to which proper coercive force (IHc) increases by content of Ga, and the Curie point (Tc) falls. The good sintering mold permanent magnet of the thermal stability characterized by Ga contained in a sintering process forming the liquid phase with a rare earth rich phase, and coming to be sintered.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention has the operation to which the main phase is an R2Fe14B mold intermetallic compound, proper coercive force (IHc) increases by content of Ga, and the Curie point (Tc) falls, by Ga to contain forming the liquid phase with R rich phase, and coming to sinter it in a sintering process, raises IHc remarkably and relates to the sintering mold permanent magnet which gave very good thermal stability.

[0002]

[Description of the Prior Art] Development is progressing as a new presentation system from which magnetic properties with a R-Fe-B system permanent magnet ingredient more expensive than a R-Co system permanent magnet ingredient are acquired, and much invention is proposed. For example, as for Nd(Fe 0.91B0.09)5.67], maximum magnetic energy (product BH) max has acquired the magnetic properties to which 35MGOe(s) and the proper coercive force IHc reach 10KOe(s) by the Nd15Fe77B8[empirical formula display (J. Appl.Phys.55(6) 2083 (1984) reference.).

However, the R-Fe-B system permanent magnet proposed in early stages of development has low therefore the fault [Curie point / (Tc)] that thermal stability is bad. Namely, with the R-Fe-B system permanent magnet ingredient proposed in early stages of development to having about 800-degree C Tc in the

permanent magnet of the conventional R-Co system, Tc is usually about 300 degrees C, and it is very as the lowest as about 370 degrees C (refer to JP,59-46008,A). Therefore, thermal stability was inadequate and there was a difficulty in use under the environment where ambient temperature is high. Two of enabling it to bear even if there is a demagnetized part in an elevated temperature as a means to solve it, raising direct Tc and by making sufficiently high proper coercive force (IHc) in a room temperature are known.

[0003] The attempt which raises Tc by permuting a part of Fe by Co as the former was made. Consequently, the effectiveness that also until would raise it at 800 degrees C above 400 degrees C if magnetic properties are sacrificed for Tc was accepted (refer to JP,59-64733,A). As the latter, addition of aluminum, Ti, V, Cr, Mn, Zn, Hf, Nb, Ta, Mo, germanium, Sb, Sn, Bi, nickel, etc. has been performed. aluminum is confirmed to the improvement in IHc especially (refer to JP,59-89401,A and a No. 77960 [60 to] official report). a part of Nd by heavy-rare-earth element still like Tb, Dy, and Ho -- it is proposed in order to improve IHc, holding a maximum energy product [(BH) max] with a high permutation, and that whose IHc is 9KOe extent at the time of (BH) max of about 30 MGOe(s) increases to 12-18KOe (refer to JP,60-32306,A and a No. 34005 [60 to] official report). In addition, compound addition of Co and aluminum is proposed as a means of the improvement in thermal stability. That is, although Tc will improve if a part of Fe is permuted by Co, the fall of the opposite side IHc cannot be denied. It is considered for a sludge with the magnetism expressed with Nd(Fe, Co) 2 appearing in the grain boundary, and a reverse magnetic domain's occurring, and falling IHc. Then, the attempt which does not generate a reverse magnetic domain is also performed by making the phase expressed with nonmagnetic Nd(Fe, Co, aluminum) 2 to Co by carrying out compound addition of the aluminum appear (Appl. Phys.Lett.48(19), 1309 (1986)).

[0004]

[Problem(s) to be Solved by the Invention] However, there is a trouble described below in the above-mentioned conventional technique.

** In order [of Fe by Co] to reduce a crystal magnetic anisotropy in part in the case of a permutation, fall IHc. Moreover, there are cost quantity and supply anxiety from a raw material side.

** Except for nickel, when adding Ai, Ti, V, nickel, etc., since it is a non-magnetic material, a lot of addition invites the fall of residual magnetic flux density 4pilr, and lowers (BH) max. Although nickel is also a ferromagnetic ingredient, since the magnetic moment is small, 4pilr is fallen after all.

** When adding a heavy-rare-earth element, since it is very expensive, it is accompanied by the remarkable rise of cost. In addition to resource-scarcity, it is because there are few applications other than a permanent magnet.

** When carrying out compound addition of Co and the aluminum, addition of aluminum is inferior to the thermal stability in the elevated temperature in 100 degrees C or more in order to reduce Tc remarkably. in addition, IHc of the R-Fe-B system magnet which carried out compound addition of Co and the aluminum -- at most -- it is only 12KOe extent.

[0005] Therefore, the technical problem of this invention is offering the sintering mold permanent magnet which raised IHc remarkably and gave very good thermal stability by forming the liquid phase and being sintered with the rare earth rich phase in which the main phase is an R2Fe14B mold intermetallic compound, and Ga which has the operation to which proper coercive force (IHc) increases by content of Ga, and Curie temperature (Tc) falls, and is contained encloses the main phase at the time of sintering.

[0006]

[Means for Solving the Problem] this invention which solved the above-mentioned conventional technical problem -- an atomic ratio -- formula R(Fe1-x-y-z-uCoxByGazMu) A (here -- R -- one sort or two sorts or more of combination of the rare earth elements of Nd, Pr, and Ce and others --) M One sort or two sorts or more of combination of Nb, W, V, Ta, and Mo, It is expressed with 0< x<=0.7, 0.02<=y<=0.3, 0< z<=0.15, 0<=u<=0.1, and 4.0<=A<=7.5. The main phase is an R2Fe14B mold intermetallic compound, and it has the operation to

which proper coercive force (IHc) increases by content of Ga, and the Curie point (Tc) falls. Ga contained in a sintering process is the good sintering mold permanent magnet of the thermal stability characterized by forming the liquid phase with the rare earth rich phase which encloses the main phase, and coming to be sintered. In the above and this invention magnet, it is more desirable from the point of thermal stability to be referred to as 0< x<=0.7, 0.02<=y<=0.3, 0.001<=z<=0.15, 0<=u<=0.1, and 4.0<=A<=7.5. Moreover, it is desirable especially from the point of improvement in thermal stability to be referred to as 0< x<=0.39, 0.03<=y<=0.2, 0.002<=z<=0.1, 0.002<=u<=0.04, and 4.5<=A<=7. Moreover, it is desirable in order that it may obtain good thermal stability that R sets to 0< x<=0.39, 0.03<=y<=0.2, 0.002<=z<=0.1, and 4.5<=A<=7 by Nd in the case of u= 0.

[0007] Rare earth elements R are the rare earth elements of Nd, Pr, and Ce and others, and a light-rare-earth element like Pr and Ce or a heavy-rare-earth element like Dy can permute them in part by making especially Nd into a subject. In addition, heavy-rare-earth elements, such as Ho and Tb, can also be used. If it exceeds 98% at the rate of an atomic ratio in permuting a part of Nd by Pr, in 4pilr's falling and permuting a part of Nd by Ce, if 30% is exceeded at the rate of an atomic ratio, 4pilr will fall. In permuting a part of Nd by Dy, at less than 3%, there is no improvement effectiveness in IHc, i.e., thermal stability, at the rate of an atomic ratio, there is most desirable effectiveness by 25% or less of permutation 5% or more, but the permutation exceeding 40% is not desirable in order it to fall 4pilr.

[0008] In this invention, if the content y of Boron B is less than 0.02, Tc will become low and sufficient coercive force will not be acquired. On the other hand, if y exceeds 0.3, 4pils will fall, and the phase which has a bad influence on magnetic properties appears. therefore, y -- 0.02-0.3 -- it is -- more -- desirable -- 0.03 to 0.2 -- it is 0.04-0.15 most preferably.

[0009] In this invention, addition of Ga has effectiveness remarkable in the improvement in IHc. It is thought that relation has this effectiveness closely with

R rich phase which encloses the main phases (intermetallic-compound Nd2Fe14B etc.) of a R-Fe-B system magnet. In order to secure good thermal stability, the content z of Ga is good to be referred to as 0< z<=0.15, it is more desirable to be referred to as 0.001<=z<=0.15, and especially the thing set to 0.005<=z<=0.05 is [it is still more desirable to be referred to as 0.002<=z<=0.10, and] desirable [the content]. It presents a remarkable reduction of Tc as saturation magnetization 4pils and is not desirable if the content z of Ga exceeds 0.15.

[0010] In this invention, Co is indispensable, and since there is the improvement effectiveness in Tc, effectiveness is in the improvement which it was at the time of thermal stability by carrying out compound addition with Ga. if the content of Co shown by x exceeds 0.7 -- magnetic 4pi -- Ir and IHc fall and are not desirable. It reaches 4pilr with IHc, and the desirable upper limit of Co for good balance of Tc is 0.39, and is 0.25 most preferably.

[0011] To this invention magnet, alloying element M:Nb, and W, V, Ta and Mo can be added for big and rough-ized prevention of crystal grain. Especially, the effectiveness of Nb and W is most excellent. Although addition of Nb falls 4pilr a little, Ga does not reduce 4pilr. Moreover, since Nb has effectiveness also in corrosion-resistant improvement, it is a very effective element for the high heatproof permanent magnet comparatively exposed to an elevated temperature. an atomic ratio -- formula R(Fe1-x-y-z-uCoxByGazMu) A (here -- R -- one sort or two sorts or more of combination of rare earth elements --) M One sort or two sorts or more of combination of Nb, W, V, Ta, and Mo, It is expressed with 0< x<=0.7, 0.02<=y<=0.3, 0< z<=0.15, 0<=u<=0.1, and 4.0<=A<=7.5, M is Nb, when a content u is less than 0.001, sufficient improvement effectiveness of IHc is not acquired, and sufficient corrosion resistance is not shown. On the other hand, when exceeding 0.1, reduction which is not desirable as for Tc is invited as 4pilr. The more desirable range of Nb is 0.002-0.04. Addition of W also improves thermal stability remarkably. When the amount of W shown by u exceeds 0.1, it reaches 4pils and IHc falls remarkably. And sufficient improvement effectiveness

of IHc is not acquired at the time less than of 0.001. More desirable range is 0.002-0.04. Addition of V, Ta, and Mo is also effective, when u is less than 0.001, sufficient improvement effectiveness in IHc is not acquired, but when exceeding 0.1, 4pils decreases remarkably. More desirable range is 0.002-0.04.

[0012] the time of 4pils being low and exceeding 7.5 in this invention, when A is less than four -- Fe and Co -- a rich phase appears and coercive force is reduced remarkably. therefore, A -- 4-7.5 -- it is -- more -- desirable -- 4.5-7 -- it is 5.0-6.8 most preferably.

[0013]

[Embodiment of the Invention] Hereafter, an example explains this invention.

[0014] (Example 1) Nd (Fe0.70Co0.2B0.07M0.03)6.5 (however, M=B, any one sort of aluminum, Si, P, Ti, V, Cr, Mn, Cu, Ga, germanium, Zr, Nb, Mo, Ag, In, Sb, and the W) -- the alloy of a presentation was produced by the arc dissolution. Coarse grinding of the obtained ingot was carried out by the stamp mill and the disc mill. It pulverized with the jet mill, using N2 gas as tumbling media, and pulverizing powder with a grinding grain size of 3.5 micrometers (FSSS) was obtained. Horizontal magnetic field shaping (the press direction and the direction of a magnetic field intersect perpendicularly) of the obtained raw material powder was carried out all over the magnetic field of 15KOe(s). 2t /of compacting pressure was [cm] 2. This Plastic solid was sintered in the vacuum for 1090 degree-Cx 2 hours. At 500-900 degrees C, heat treatment was quenched, after carrying out heating maintenance for 1 hour. The obtained result is shown in Table 1. That to which IHc exceeds 10KOe(s) in 19 examined elements is only Ga. Thus, Ga is very effective in improvement in coercive force. In Table 1, to Tc=468 degree C in the M=Ga addition belonging to this invention, it is Tc=477 degree C of the thing of M=B addition, and it turns out that it has the operation to which Tc falls a little by content of Ga.

[0015]

[Table 1]

Nd (Fe0.7 Co 0.2 B0.07M0.03)0.5 磁石の磁気特性

M	B	Al	Si	P	Ti	V	Cr	Mn	Ni	Cu
4πIs (KG)	13.31	12.61	12.80	12.90	12.77	13.19	12.30	12.50	12.95	12.57
4πIr (KG)	12.80	12.45	12.65	0	11.80	13.05	12.15	12.34	12.78	12.32
iHc (KOe)	2.6	8.5	7.0	0	4.8	4.9	5.1	5.3	4.1	3.0
(BH)max (MGOe)	13	33.5	32.0	0	24.0	25.5	28.0	24.0	13.1	18.1
Tc (℃)	477	460	458	482	467	470	478	431	485	481

Tc：キュリー点

M	Ga	Ge	Zr	Nb	Mo	Ag	In	Sb	W
4πIs (KG)	12.60	12.72	12.30	13.03	13.10	13.22	12.70	12.05	12.95
4πIr (KG)	12.50	~0	10.5	12.9	~0	~0	~0	~0	12.75
iHc (KOe)	16.0	~0	4.3	6.9	~0	~0	~0	~0	6.0
(BH)max (MGOe)	35.0	~0	12.1	35.1	~0	~0	~0	~0	32.2
Tc (℃)	468	479	466	477	465	483	488	482	476

[0016] (Example 2) as Nd (Fe0.9-xCoxB0.07Ga0.03)5.8 (x=0-0.75) and the example of a comparison -- Nd (Fe0.93-xCoxB0.07)5.8 (x=0-0.25) and Nd0.9Dy0.1 (Fe0.93-xCoxB0.07) 5.8 (x=0-0.25) -- the alloy of a presentation -- the same approach as an example 1 -- coarse grinding -- it pulverized, sintered and heat-treated. The obtained result is shown in Table 2, Table 3, and Table 4. These results show that the addition x of Co is suitable or less by 0.7.

[0017]

[Table 2]

Nd (Fe0.9-x Co x B0.07 Ga0.03)5.8 磁石の磁気特性

x / 磁気特性	0	0.01	0.05	0.25	0.39	0.7	0.75
4πIr (KG)	12.6	12.58	12.55	12.09	12.02	10.7	9.2
iHc (KOe)	20.6	19.9	19.6	16.5	14.8	12.3	11.0 s
(BH)max (MGOe)	37.0	36.6	36.2	33.2	32.8	26.6	19.2

[0018]

[Table 3]

Nd $(Fe_{0.93-x}Co_xB_{0.07})_{5.8}$ 磁石の磁気特性（比較例）

磁気特性 \ x	0	0.01	0.05	0.25
4πIr (KG)	13.4	13.32	13.32	12.88
iHc (KOe)	9.0	8.8	8.8	7.1
(BH)max (MGOe)	42.1	41.5	41.5	38.8

[0019]

[Table 4]

$Nd_{0.9}Dy_{0.1}(Fe_{0.93-x}Co_xB_{0.07})_{5.8}$ 磁石の磁気特性（比較例）

磁気特性 \ x	0	0.01	0.05	0.25
4πIr (KG)	12.62	12.59	12.51	12.11
iHc (KOe)	15.6	15.4	15.0	11.6
(BH)max (MGOe)	38.2	37.9	37.5	34.3

[0020] Next, they are after heating maintenance and open for 30 minutes to predetermined temperature about a sample in case the amounts of Co(es) are 0 and 0.2. Change of flux was measured and thermal stability was investigated. The sample used for measurement processes the configuration used as permeance coefficient Pc=-2. The obtained result is shown in drawing 1 and drawing 2. If Ga is added clearly, coercive force will be high and thermal stability will improve very much.

[0021] (Example 3) Nd (Fe0.7Co0.2B0.08Ga0.02) -- A (A=3.7-7.7) and Nd (Fe 0.92B0.08) -- A (A=5.6-6.6) -- the alloy of a presentation -- the same approach as an example 1 -- coarse grinding -- it pulverized, sintered and heat-treated. The obtained result is shown in Table 5 (a) and Table 5 (b). Or more in A= 6.2, by carrying out compound addition of Co and the Ga, A= 6.6 or more, high coercive force is acquired and, in the case of Nd-Fe-B the system of 3 yuan, a high property is acquired to most of IHc and (BH) max being zero. It became a cause that Nd rich phase committed as the liquid phase in a sintering process by oxidization of Nd or more in A= 6.2 decreases, and the Nd-Fe-B system of 3 yuan has barred generating of coercive force. . On the other hand, in Co and Ga compound addition, it works as the liquid phase instead of being Nd to which Ga

oxidized, and high coercive force is generated.

[0022]

[Table 5]

(a) Nd ($Fe_{0.7}$ $Co_{0.2}$ $B_{0.08}$ $Ga_{0.02}$)$_A$ 磁石の磁気特性

磁気特性 \ A	3.7	4.0	5.6	6.6	7.5	7.7
4πIr (KG)	9.2	10.4	12.25	12.7	13.8	14.0
iHc (KOe)	17.5	17.3	15.4	12.0	10.7	5.9
(BH) max (MGOe)	19.2	25.0	35.8	37.1	45.6	15.8

(b) Nd ($Fe_{0.92}$ $B_{0.08}$)$_A$ 磁石の磁気特性 (比較例)

磁気特性 \ A	5.6	5.8	6.0	6.2	6.4	6.6
4πIr (KG)	13.04	13.2	13.4	13.6	13.7	13.8
iHc (KOe)	10.0	9.3	9.0	0	0	0
(BH) max (MGOe)	40.2	41.3	42.6	0	0	0

[0023] (Example 4) 5.5 (z=0-0.18) -- by the same approach as an example 1, it was dissolved and ground, and was fabricated and the alloy was sintered (Fe0.86-zCo0.06B0.08GaZ). (Nd0.8Dy0.2) Furthermore, after heating maintenance of 900 degree-Cx 2 hours, after cooling to ordinary temperature by 1.5 degrees C / min, aging treatment of 580 degree-Cx 1 hour was performed in Ar air current, and it cooled underwater. The acquired magnetic properties are shown in Table 6, and the irreversible demagnetizing factor by 220-degree-C heating is shown in Table 7. It turns out that IHc goes up sharply although 4pilr and (BH) max fall by addition of Ga, and thermal resistance is also improving. Since 4pilr will decrease notably if effectiveness is accepted by 0.001 and 0.15 is exceeded, it is more desirable to be referred to as 0.001<=z<=0.15, 0< z<=0.15 is desirable, and especially the thing set to 0.005<=z<=0.05 is [as for the addition z of Ga, it is still more desirable to be referred to as 0.002<=z<=0.10, and] desirable [the addition].

[0024]

[Table 6]

$(Nd_{0.8}Dy_{0.2})(Fe_{0.84-z}Co_{0.06}B_{0.08}Ga_z)_{5.5}$

z	4πIr (G)	bHc (Oe)	iHc (Oe)	(BH) max (MGOe)
0	11050	10700	22500	29.5
0.001	11000	10650	23200	29.6
0.002	10900	10600	23500	28.8
0.005	10740	10400	25200	27.9
0.01	10600	10200	26500	27.2
0.05	9400	9600	27200	20.1
0.10	8900	8600	> 28000	18.9
0.15	8000	7800	> 28000	15.3
0.18	7200	7600	> 28000	11.0

[0025]

[Table 7]

$(Nd_{0.8}Dy_{0.2})(Fe_{0.84-z}Co_{0.06}B_{0.08}Ga_z)_{5.5}$

z	220℃加熱による不可逆減磁率 (%, Pc =−2)
0	10.1
0.001	9.3
0.002	7.5
0.005	5.1
0.01	2.7
0.05	1.9
0.10	0.3
0.15	0.1
0.18	0.1

[0026] (Example 5) 5.5 (z=0-0.06) -- by the same approach as an example 1, it was dissolved, ground and fabricated, and was sintered and the alloy was heat-treated (Fe0.845-zCo0.06B0.08Nb0.015GaZ). (Nd0.9Dy0.1) The acquired magnetic properties are shown in Table 8, and the irreversible demagnetizing factor by 220-degree-C heating is shown in Table 9. When there are few amounts of Dy permutations, it turns out that thermal stability improves by addition of Ga. Moreover, the addition of Ga is 0. When effectiveness is accepted by 001 and 0.15 is exceeded, it turns out that 4pilr decreases remarkably. Therefore, as for the addition z of Ga, it turns out that it is more desirable to be referred to as 0.001<=z<=0.15, 0< z<=0.15 is desirable, and especially the thing set to 0.005<=z<=0.05 is [it is still more desirable to be referred to as 0.002<=z<=0.10, and] desirable.

[0027]

[Table 8]

$(Nd_{0.9}Dy_{0.1})(Fe_{0.845-z}Co_{0.04}B_{0.08}Nb_{0.015}Ga_z)_{5.5}$

z	4πIr (G)	bHc (Oe)	iHc (Oe)	(BH)max (MGOe)
0	11850	11550	15200	34.1
0.001	11800	15200	16700	33.8
0.002	11670	11440	17400	32.4
0.005	11580	11260	18760	32.0
0.01	11400	11000	19800	31.6
0.05	10550	10100	> 28000	26.9
0.10	10000	9880	> 28000	25.2
0.15	8550	8320	> 28000	22.4
0.18	7560	7240	> 28000	20.8

[0028]

[Table 9]

$(Nd_{0.9}Dy_{0.1})(Fe_{0.845-z}Co_{0.04}B_{0.08}Nb_{0.015}Ga_z)_{5.5}$

z	220℃加熱による不可逆減磁率(%, Pc=−2)
0	38.1
0.001	34.4
0.002	32.6
0.005	29.7
0.01	20.3
0.05	0.7
0.10	0.6
0.15	0.6
0.18	0.5

[0029]

[Effect of the Invention] As mentioned above, as shown in the example As opposed to coercive force decreasing remarkably, since it is sintered after it became a cause that R rich phase committed as the liquid phase in a sintering process by oxidization of the rare earth elements R contained in the conventional R-Fe-B system sintered magnet decreases and content R minutes which is not oxidized [effective] have run short Since Ga contained so that lack of effective non-oxidized content R minutes may be compensated in a sintering process in this invention magnet exists as the liquid phase and sintering advances, very high IHc is discovered, it is conspicuous, and good heat stability can be acquired.

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is drawing showing the irreversible demagnetizing factor to whenever [stoving temperature / of Nd-Fe-B, Nd-Dy-Fe-B, and a Nd-Fe-B-Ga magnet].

[Drawing 2] It is drawing showing the irreversible demagnetizing factor to whenever [stoving temperature / of Nd-Fe-Co-B, Nd-Dy-Fe-Co-B, and a Nd-Fe-Co-B-Ga magnet].

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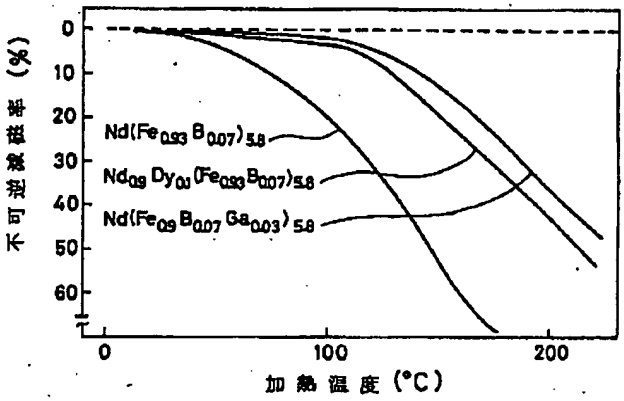
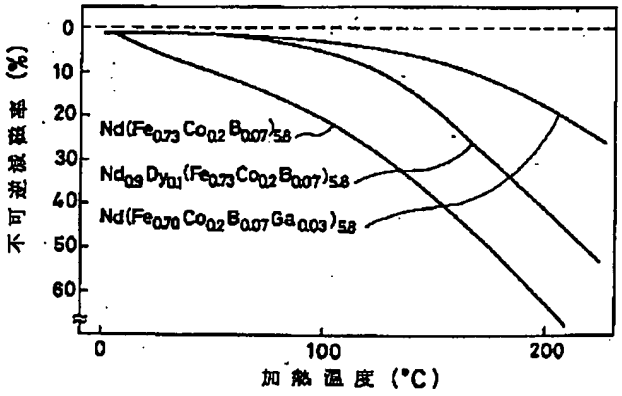
DRAWINGS

[Drawing 1]



[Drawing 2]



[Translation done.]